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A MODEL FOR ESTIMATING MILITARY PERSONNEL ROTATION BASE REQUIREMENTS

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PREFACE

This Memorandum describes the problems connected with rotating Air Force personnel between ConUS and overseas locations. It presents and explains the functioning of a Rotation Base Model for estimating certain manpower requirements caused by rotation. The model was developed because of RAND interest in the effect of OSD Civilianization Programs on the Air Force, and represents an initial attempt to calculate Air Force rotation base manpower requirements by means of mathematical programming. Use of the model will indicate those important factors in the force management process that must be taken into account in future quantitative models. Quantitative explanations of the model are contained in appendices, and only minimal knowledge of the Air Force Personnel and Manpower structure is assumed in the remainder of the Memorandum.

The model was initially briefed to the Manpower and Personnel offices of the Air Staff and to the Military Personnel Center in March 1967. This Memorandum is intended for those planners in the Manpower and Personnel area who must estimate the required size and composition of the Air Force. It should also be thought-provoking to analysts interested in a problem that has barely been considered, and that can be approached from a variety of methodological points of view.

SUMMARY

Approximately one-third of all Air Force personnel are overseas and two-thirds are in the continental United States (ConUS). It has been traditional policy to allow servicemen returning from overseas a "reasonably" long tour in the United States prior to the next overseas tour; so that ConUS tours are generally about twice as long as overseas tours. In theory, then, the tour groups are balanced. While the presence or absence of dependents and area desirability affect actual overseas tour lengths and prevent precise overall statements, for certain groups of specialties the picture is one of imbalance. There is a strong demand for specialty groups such as armament personnel and postal personnel in short-tour overseas areas without a balancing demand for these personnel types in the ConUS. This creates the problem of maintaining a "rotation base"--a reservoir of personnel from which to support overseas requirements.

In practice, ConUS tour lengths in the imbalanced specialties are adjusted, and personnel assignment and training policies are modified to cope with overseas requirements. The Air Force manpower structure adapts to imbalances through a loosely coordinated group of offices. The imbalance figures computed by the Military Personnel Center are used most directly by the Directorate of Manpower and Organization. This Directorate attempts to reduce imbalances by replacing overseas military authorizations with civilian authorizations, or ConUS civilian authorizations with military authorizations. The Directorate of Personnel Training uses the imbalance computations to derive projections of the number of personnel who must be cross-trained in order to meet requirements.

The current method of computing imbalances (designed by Major Harry F. Kagan, Military Personnel Center) is adequate for the continuous policy review cycle described above. But occasions arise--as in the OSD Civilianization Programs underway since August 1965--which make it necessary to compute a numerical lower bound of the military forces required in ConUS to support rotation requirements. The model described here takes account of the cross-training and substitutability

of personnel and yields a more precise estimate of this lower bound than the Kagan model. Its function is not to remedy imbalances by substituting military personnel for civilians, or vice versa, nor to generate optimal rotation or training policies. It merely accounts for numerical requirements and stated cross-training and assignment policies in existence at a point in time, and indicates the military manpower pool required to support those requirements.

The model's numerical results are obtained through a network of "assignment classes" and "tour areas." Assignment classes are arbitrary groupings of grades, skill levels, and Air Force Specialty Codes (AFSCs). Tour areas are collections of bases of the same type and tour length. Each assignment-class/tour-area pair specifies a "node" in the network. For example, such a pair might be: staff sergeants, jet-engine mechanics, at skill level 5, assigned to 36-month tours in Europe. The arcs in the network represent possible assignment actions given cross-training and assignment policies. A network flow algorithm then generates that set of rotation and cross-training actions that meets requirements at all bases, insures that individuals do not stay in overseas areas beyond specified overseas tour lengths, and minimizes the total staff in training and assigned to all bases.

The model and approach described here can be extended to obtain more accurate estimates of military manpower requirements by including other types of management actions now taken by the Air Force to reduce imbalances, such as retention of dual AFSCs. Inclusion of pipeline times would further refine estimates of requirements. The existing model and the family of possible successors can also be used to examine the size of the required rotation base as a function of tour lengths and personnel assignment policies.

ACKNOWLEDGEMENTS

The authors appreciate the assistance provided by the many Air Force officers who patiently explained the operation of the personnel system. We retain responsibility for any remaining errors of description, and of course we alone are responsible for any interpretation present in this Memorandum.

In attaching the name "Kagan Model" to the initial Air Force rotation imbalance computations, we are acknowledging Major Kagan's original and valuable quantitative contribution in this area.

CONTENTS

I. INTRODUCTION

THE ROTATION BASE PROBLEM

The United States Air Force requires personnel at locations scattered throughout the world. Approximately one-third of the entire force is assigned to overseas areas, and of this portion approximately 25 percent are assigned to remote or isolated locations. The individuals required to man this force comprise four operating skill levels in over 45 different occupational specialty fields. Requirements by specialty and skill mix differ from one geographic area to another. For example, more tactical armament specialists are required in overseas areas than in the continental United States (ConUS), while strategic missile personnel are seldom required out of ConUS.

The tour length, or time a given airman is assigned to a given base, varies both by geographic area and, in practice, by specialty. Specified tour lengths reflect the desirability of assignment in a particular geographical region, and range from 12 months in isolated or remote areas to 48 months (with some extensions possible) in areas deemed to possess "acceptable patterns of American living."*

While a multitude of personnel assignment policies guide and constrain the rotation situation, the underlying philosophy is the attempt to share desirable and undesirable duty by rotating people back to the United States between periods of overseas duty. At any point in time only a portion of the people in each specialty group in ConUS can be assigned overseas. Personnel are not assigned overseas who have only recently joined the service, who have recently changed bases in ConUS, who are in student or "controlled" tours, or who are awaiting separation. These restrictions on overseas movement lead to an "available" or "eligible" fraction.

While assignment policy permits voluntary consecutive overseas tours in a variety of cases, the central policy intent is to return overseas personnel to reasonably long tours in ConUS. The overriding

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*Overseas Duty of Military Personnel, Department of Defense, DOD Directive 1315.7, April 6, 1963.

goal, of course, is to meet mission requirements, and this frequently necessitates modifying tour lengths, eligibility rules, and training programs. The magnitude of the assignment effort is startling. In fiscal 1966, approximately 300,000 assignment actions involving moves occurred.

The rotation process described thus far leads to an aggregated model, and permits a straightforward estimate of the ConUS personnel base required to support rotation. If ConUS tour lengths are to be about twice overseas tour lengths, about twice as many military personnel are required in ConUS as overseas simply to support overseas requirements. There are a variety of elements that complicate this two-to-one ratio. The length of actual overseas tours is increased if a man's dependents accompany him. Personnel moving into new assignments frequently require formal training prior to assignment, and they also take leave between assignments. Personnel completing assignments in ConUS or overseas may choose to leave the Air Force entirely, and are thus not available for reassignment. New personnel enlisted to replace losses must undergo formal basic and technical training. Furthermore, the manpower requirements by specialty and skill are not constant over time but vary as organizations, missions, and weapon systems change. Finally in an effort to cope efficiently with this continual flood of reassignment actions, the Air Force utilizes cross-training extensively. That is, personnel in one specialty who are completing an assignment overseas, but who are not required in that specialty in ConUS, will be reassigned to another specialty, possibly requiring formal cross-training prior to the actual assignment. In specialties where retention rates are fairly high ("loss" rates are low), this results in a number of "dual-qualified" personnel who can be assigned into either of two specialties. The existence of such groups complicates estimation of the required ConUS rotation base.

The rotation process requires study because of the cost involved, both simple transportation cost and the productivity loss that over 300,000 moves per year entail. Even estimates of the magnitude and composition of the required military personnel rotation base are

important. While the results are useful in normal force planning, force size during the 1950-1965 era never required justification on the basis of supporting rotation. In 1965, however, with the initiation of an OSD civilianization program to ensure that military personnel were not performing functions that civilians could perform, the question of basic military requirements became pertinent. A variety of factors dictate manning by purely military personnel--combat, discipline, security, training, and ceremony--but among the most important factors are the military rotation base, the military career progression base, and the military cadre or combat expansion base.

The rotation base has already been defined. The military career progression base is the set of positions within the structure of the Air Force through which Air Force personnel must pass in order to gain experience for other positions. For instance, a future civilianization program could not remove all jet engine technician positions from the military structure without preventing military personnel from acquiring the experience necessary to progress to jet engine maintenance superintendent.

The basic military cadre is the organizational core required to deploy and support combat forces and to provide the training capacity necessary to replenish those forces. Therefore the question of the required military rotation base is a relevant one. This Memorandum presents a model that applies to that question.

TREATMENT OF THE ROTATION SITUATION IN PRACTICE

Several offices of the Air Force continually observe and manage the rotation situation, and adjust rotational imbalances. The Military Personnel Center (MPC) at Randolph Air Force Base, Texas, distributes and administers the existing military personnel resource in accordance with established Air Force policies. MPC notes the overseas numerical requirements and tour length for each specialty and determines the staff required in ConUS to support rotation into that specialty under existing policies. MPC then notes the stated requirement for that specialty in ConUS. If the rotation base required in ConUS exceeds the authorized number in ConUS, the specialty is "imbalanced." From MPC

the balance calculations move to the Directorates of Personnel Training and Education, Personnel Planning, and Manpower and Organization, in United States Air Force Headquarters. Training estimates the number of new accessions that must enter initial technical training and cross-training to meet the requirements in each imbalanced specialty. Personnel Plans examines and modifies personnel policy in light of the balance data. Personnel are restricted from movement into fields with ConUS "overages" and directed into fields with overseas shortages. Personnel policies with eligibility implications are reviewed to alleviate problems in critical areas. Finally, Manpower examines the distribution of civilian and military manpower authorizations in the imbalanced specialties, and attempts to increase the number of civilians used overseas to reduce rotation requirements and increase the number of military authorizations in ConUS to provide spaces for the rotation base. Thus manpower authorizations, personnel policies, and training policies continually adapt to meet Air Force requirements.

ESTIMATES OF THE ROTATION BASE REQUIREMENT

Until 1965 no precise estimator of the overall military personnel rotation base requirement was available. The overall two-to-one ConUS-Overseas ratio appeared generally consistent with personnel assignment policies. To handle additional ConUS manpower authorizations for pipelines, training, transients, and losses, the 2.33-to-1 ConUS-Overseas ratio was frequently cited as desirable. In 1965 the Military Personnel Center examined, by specialty class, the correlation between ConUS tour lengths and the ratio of overseas to ConUS requirements. The obvious expectation was that low ratios lead to satisfactory ConUS tour lengths. The finding was that the time between ConUS and overseas tours varied widely between grades in the same skill, and between the same grades in differing skills; and for a single grade and skill, varied widely over time. In an effort to compute rotation base requirements based on a stabilized ConUS tour length, Major Harry F. Kagan, Military Personnel Center, constructed a model of the rotation process, which could estimate the ConUS manpower positions required to support overseas

needs, given existing overseas assignment policies. This computation includes tour lengths at different locations, numerical manpower requirements by assignment class, and the eligibility of individual personnel for overseas movement. The Kagan model essentially pictures rotation as movement within a single AFSC group from ConUS to overseas points, and then back to ConUS.* Kagan's model is currently used by both the Military Personnel Center to provide officer imbalance data and by Personnel Planning to provide airman imbalance data. In order to further refine the estimate of the required rotation base, it became desirable to increase the number of factors considered in the computation. The additional factor considered was the substitutability between different specialties, perhaps through cross-training.

The rotation problem was thus pictured as a network of nodes and directed arcs, the nodes being the various specialties required at various geographic locations, and the arcs connecting all pairs of nodes between which assignment actions were possible, including assignment through cross-training. The rotation model constructed minimizes total manpower required while meeting manpower authorizations at all bases. It achieves this minimization by scheduling all reassignment and cross-training actions for personnel completing tours.

The object in constructing this initial model was to derive an estimate of rotation base requirements that takes account of the Air Force capability to cross-train individuals and assign them into specialties similar to the primary specialty. Given the model described in this Memorandum, the data at the Air Force Military Personnel Center, and estimates of cross-training times between specialties, it

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*A concurrent rotation model considers more constraining personnel policies. It was developed by R. C. Sorenson, Logical Model Representing Flow in the U.S. Army: Considerations Relative to Reduction of Turbulence, U.S. Army Personnel Research Office, Technical Research Note 156, July 1965. Sorenson's formulation permits certain types of consecutive overseas tours, prevents other types of consecutive overseas tours, and controls the fractions of the force which may receive various types of assignments. The Sorenson work resulted in a series of nomographs which relate tour lengths in ConUS to the fraction of the force that can receive certain types of assignments.

is possible to estimate the rotation base for the entire Air Force or for any subset such as the Air Defense Command or the Maintenance Career Area.

The remainder of this Memorandum discusses the structure of rotation models in general,* and the capabilities of the existing Kagan and Sorenson approaches. It then describes in more detail the initial RAND Rotation Base Model (RBM-I) and indicates some applications and possible extensions. Appendices are included that contain the quantitative and logical model structure, the data formats, input control cards, output reports of the computer program, and a sample problem. The RAND Corporation will supply the computer program to qualified requestors.

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*Rotation models may be static or dynamic; may be descriptive or normative; may concern themselves with policy modification or may merely reflect existing policy; may take requirements as known or uncertain; and may be directed at many criteria.

II. MODELS OF THE ROTATION PROCESS

The rotation process can be modeled in a variety of ways. It can be viewed as a dynamic process in which requirements are assumed known over time, or it can be viewed as a process in equilibrium with unchanging requirements. The dynamic approach will indicate surges, bottlenecks in the system, and the time-phasing of personnel. But the dynamic approach also requires a model of greater complexity, and with this complex a problem, usually must forego optimization in favor of simulation or simple description.

A rotation model may reflect fixed policies and assignment constraints that affect personnel movements or, by modifying policy variables, it may optimize some criterion measure such as total manpower or total cost. Policy variables that might be considered include the civilian-military mix by location, the extent to which cross-training is used, the control of retention rates as a function of cost, and the use of contractor services as a substitute for military personnel.

The current RAND model considers the rotation situation to be in equilibrium, and minimizes total manpower by determining a set of personnel cross-training actions. The policy variables of tour length, eligibility percentage, and retention rate are included but are fixed.

THE CURRENT AIR FORCE ROTATION INDEX

As mentioned in Sec. I, the computational treatment of the rotation base problem the Air Force now uses is the Kagan model. The model was developed to provide rotation base indices of imbalance for use by Headquarters USAF in the Phase I Civilianization programming; it utilizes personnel data available at the Military Personnel Center. Each AFSC, skill level, and grade (grouped to form an "assignment class") are considered separately. The Kagan model assumes:

1. Assignments at overseas locations are grouped by tour length.
2. Numerical manpower requirements are specified for each assignment class at each overseas location.
3. Consecutive overseas tours are negligible. Personnel rotate from overseas directly back to ConUS.

4. Pipeline times are negligible.
5. An average eligibility factor* is estimated for each assignment class. This factor is determined by personnel policies and the force composition, and includes pending separation actions, medical qualifications, deferment status, and controlled tours.

Given these assumptions, personnel return to ConUS from the different overseas locations at a rate that depends on the number of personnel assigned to the location and the tour length. Replacement personnel flow at the same rate from ConUS to these areas. The number of personnel required in the assignment class in ConUS to support rotation depends on this flow rate, the ConUS tour length, and the eligibility factor.

For any fixed assignment class,

let b_j = required number of personnel in that assignment class in some overseas location j. Assume there are M - 1 overseas tour areas.

ℓ_j = tour length in location j.

α = fraction in the specific assignment class who are eligible for overseas assignment.

X_j = number of personnel assigned to location j.

Let j = 1 denote the ConUS location for the specific assignment class. The object of the Kagan model is to determine X_1, the ConUS requirement to support the M - 1 overseas locations for the specific assignment class.

The number flowing out of each location per unit time is therefore X_j/ℓ_j. The number of consecutive overseas tours is negligible. The number of personnel in this assignment class leaving ConUS per unit time must then be

$$\sum_{j=2}^{M} \frac{X_j}{\ell_j} .$$

*The eligibility factors are determined in practice by scanning the entire personnel data file and computing the fraction of ConUS-based personnel in each assignment class eligible for overseas assignment under existing personnel policies.

Each returning person must remain in ConUS for ℓ_1 time units, and hence to support this outflow, the basic ConUS requirement is

$$\ell_1 \sum_{j=2}^{M} \frac{X_j}{\ell_j} .$$

Accessions, losses, and other constraints on overseas movement are accounted for by the eligibility factor σ. Since only the fraction σ can move overseas, the ConUS requirement becomes

$$X_1 = \frac{\ell_1}{\sigma} \sum_{j=2}^{M} \frac{X_j}{\ell_j} .$$

To minimize this, Kagan chooses $X_j = b_j$, the requirement at j, obtaining

$$X_1 = \frac{\ell_1}{\sigma} \sum_{j=2}^{M} \frac{b_j}{\ell_j} ,$$

which is the number of individuals in the particular assignment class in ConUS required to support rotation into that class at all overseas bases.

Finally, to account for existing ConUS requirements that are independent of overseas rotation base requirements, the expression for X_1 may be modified to obtain

$$X_1 = \max \left(b_1 , \frac{\ell_1}{\sigma} \sum_{j=2}^{M} \frac{b_j}{\ell_j}\right).$$

As an example consider three assignment classes and one overseas location as shown in Table 1.

Table 1

EXAMPLE OF KAGAN MODEL

Variable	Assignment Class 1	Assignment Class 2	Assignment Class 3
Overseas requirement	0	8,000	10,000
Independent ConUS requirement	75,000	15,000	0
Overseas tour length (months)	24	12	12
ConUS tour length (months)	48	48	48
Eligibility factor	1	1	1

Let X_1^i = number of ConUS personnel in assignment class i.

Considering the classes separately we find

$$X_1^1 = \max\left(75{,}000,\ 48\ \frac{0}{24}\right) = 75{,}000$$

$$X_1^2 = \max\left(15{,}000,\ 48\ \frac{8000}{12}\right) = 32{,}000$$

$$X_1^3 = \max\left(0,\ 48\ \frac{10{,}000}{12}\right) = 40{,}000$$

or that 147,000 military personnel are required in ConUS.

Kagan's model was designed to account for several of the policies and constraints causing the rotational imbalances--tour lengths, manpower requirements by area, and eligibility factors. Personnel retention rates are not considered by the Kagan model but do appear to significantly affect the magnitude of the required rotation base. Inclusion of personnel retention rates and of the simplest of the methods by which the Air Force actually copes with rotational imbalances--reassignment between specialties through cross-training--leads to the initial RAND rotation base model.*

RAND ROTATION BASE MODEL

The Kagan model computes the ConUS rotation base requirement for each assignment class separately and then obtains the total ConUS military personnel requirement by summing requirements in each assignment class. Since this procedure does not consider substitutability, it overstates the total military personnel requirement induced by rotation. Personnel can frequently be reassigned directly into related specialties. Personnel can also be cross-trained and assigned from specialties required primarily in ConUS to specialties required primarily overseas. Furthermore, airmen who receive cross-training in a new specialty do not lose qualification in their former specialty, and can be reassigned in either category.

The RAND model ignores prior training and possession of more than one specialty qualification, and concentrates only on the economies possible by cross-training prior to reassignment.

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*The Air Force has continued to refine models which estimate the required rotation base. These model developments primarily involve redefinition of the eligibility factor rather than the inclusion of cross-training. We do not consider them further in this Memorandum.

For each assignment class (AFSC, skill level, and grade) and each location, assume that there is a known and constant personnel requirement and a fixed tour length. A set of eligibility factors, α_i, can be estimated that is a function of assignment policies and accession and loss rates and that states the fraction of the personnel in ConUS assignment class i who are eligible for overseas assignment. Thus $(1 - \alpha_i)$ of those present are ineligible for overseas assignment. Assume also that cross-training times, t_{ij}, can be estimated that indicate the average time required to train a person in assignment class i into assignment class j. There are approximately 40 significant airman career areas and approximately 10 overseas tour areas we must distinguish among. By formulating the rotation base problem at this level of aggregation, computation can be handled by existing network flow algorithms.

The introduction of cross-training and substitutability does not affect rate of return from each overseas location, which must be at least b_i/ℓ_i, but may allow surplus personnel in some classes to fill requirements in others. Movement of personnel between different assignment classes may require that a training pipeline be filled. For example, if F-100 jet engine mechanics can be utilized as B-52 jet engine mechanics after two months of training, and 500 men per month are reassigned from F-100's to B-52's, 1000 people are in this training pipeline at any point in time. The possible reduction in personnel requirements arises from the existence of ConUS assignment classes with no overseas counterparts and overseas requirements with no ConUS counterparts.

With the introduction of cross-training and substitutability, the rotation problem can be viewed as flow in a network of nodes and directed arcs. The nodes represent the various assignment classes at the various geographic locations, and the arcs connect all pairs of nodes between which an assignment is possible. While it initially may appear that each node must be identified by two subscripts--an assignment class, and an area--Appendix A describes how the nodes may be numbered sequentially. This allows reference to each node by a single subscript and yet permits identification of the assignment class and location corresponding to each node. With the assignment-class/tour-area pairs renumbered to index all nodes sequentially, let y_{ij} be the flow of personnel from node i to node j.

The problem described thus far is shown in Fig. 1 for three assignment classes and one overseas location. Utilizing the notation previously developed, the rotation flow from each overseas base must be

$$(1) \qquad \sum_{j \in \text{ConUS}} y_{ij} \geq \frac{b_i}{\ell_i} \text{ for i overseas, since } X_i \geq b_i .$$

The object of the model is to minimize the total military personnel requirement. This total is composed of two elements. The first is the number of individuals in training pipelines,

$$\sum_{ij} t_{ij} y_{ij} .$$

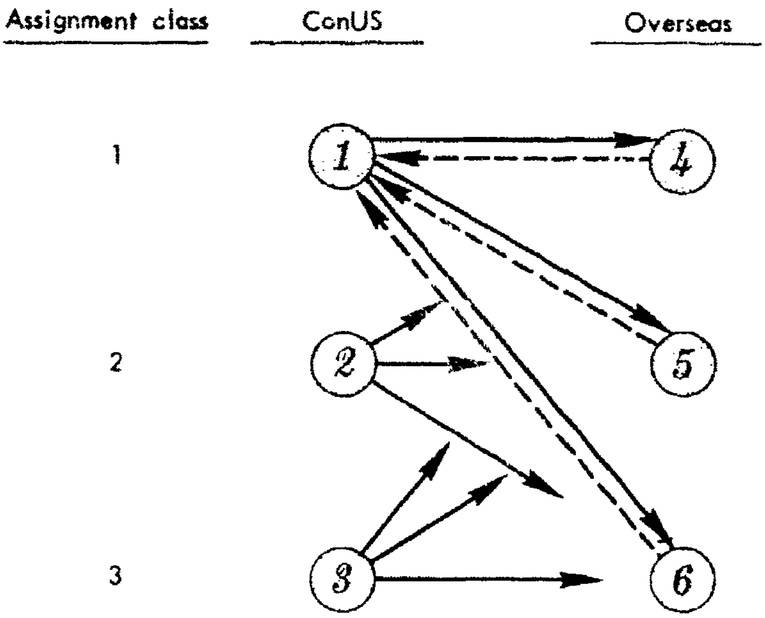

Fig. 1 -- Network description of example problem

The second is $\sum X_i$. But for each node, i, at least enough personnel must be present to match total outflow, $\sum y_{ij}$. Thus

$$\sum_i X_i = \sum_i \ell_i \sum_j y_{ij} ,$$

and the total personnel objective function to be minimized is

$$(2) \qquad \sum_i \ell_i \sum_j y_{ij} + \sum_i \sum_j t_{ij} y_{ij} .$$

Minimizing (2) subject to (1) and the usual conservation of the flow equations in a network is easily accomplished by several algorithms. However, formulation of the network to insure that only α_i percent of the personnel at a ConUS node are assigned overseas requires some ingenuity. Standard mathematical programming formulations allow constraints on variables to be stated as functions of other unknown variables. It appears natural to express the constraint that only the fraction α_i of the personnel at ConUS node i can be assigned overseas as

$$\sum_j y_{ij} \leq \alpha_i x_i .$$

But constraints on flows in networks must be stated as absolute numbers. As a first step in dealing with eligibility constraints we assume that the fraction α_i of the <u>number required</u> at node i are eligible for assignment overseas. If the number of personnel assigned to node i is greater than b_i, the entire excess is assumed eligible for overseas assignment. The network construction which represents these conditions is detailed in Appendix A.

Consider the example on page 9 together with the matrix of cross-training times in Table 2.

Table 2

CROSS-TRAINING TIMES
(In Weeks)

	Assignment Class		
Assignment Class	1	2	3
1	0	8	4
2	16	0	4
3	4	8	0

The requirements of the situation are shown in Fig. 2. Intuitively one would expect to use the large supply of personnel in assignment class 1 in ConUS to supply the class 3 requirements overseas.

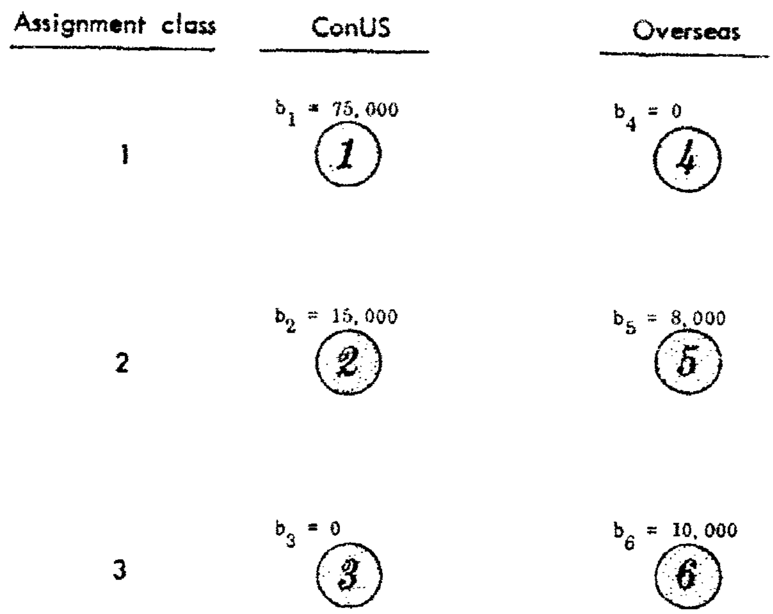

Fig. 2 -- Network of example problem with cross-training

Figure 3 shows the optimal rotation flow calculated by the Fulkerson Out-of-Kilter Algorithm.* In this rotation pattern there are 3,796 personnel in training, 75,024 on duty at ConUS assignment class 1, and 14,976 on duty at ConUS assignment class 2, a total required rotation base of 93,796 as compared to 147,000 in the original independent rotation base requirement.** While this example is admittedly extreme, it illustrates that substitutability considerations cannot be ignored in estimating rotation base requirements.

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*D. R. Fulkerson, An Out-of-Kilter Method for Minimal Cost Flow Problems, The RAND Corporation, P-1825, January 1960.

**Requirements are not exactly met in this example due to the truncation that occurs in integer arithmetic.

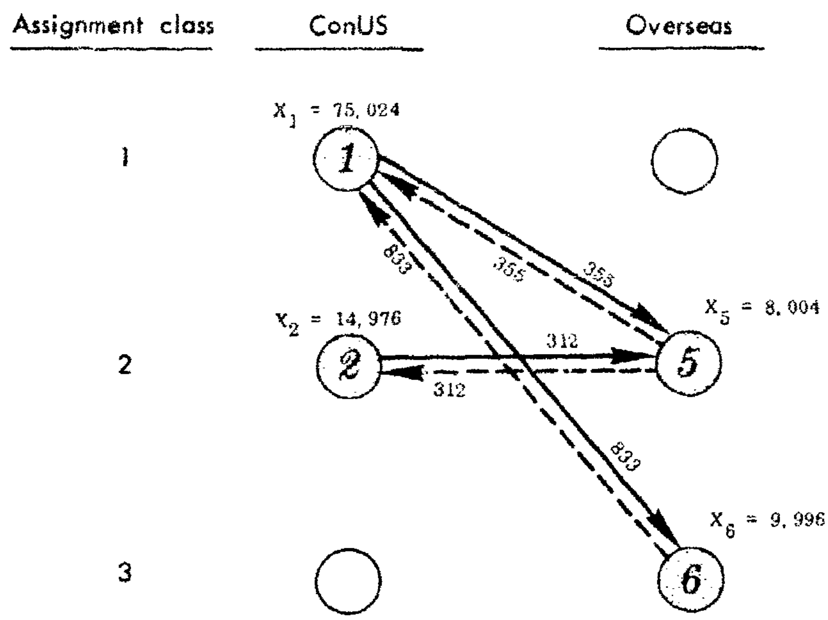


Fig. 3 -- Optimal rotation flow considering cross-training

ACCESSIONS AND LOSSES

The Rotation Base Model further generalizes the Kagan model by considering the personnel retention rate. The model assumes that personnel can be lost to the Air Force from any assignment class in any tour area at a rate that is a known constant proportion of the requirement at the location. To retain equilibrium in the system, new accessions occur in sufficient quantity to meet all losses, and are drawn into those ConUS assignment classes that lead to the minimum total personnel requirement. That is, while losses are known once requirements are known, the model optimizes accessions.

The inputs the model requires to account for losses are simply average loss rates by assignment class, and the average lead time that must transpire before a trainee is assigned to his first base as an operational resource. To see how accession and loss rates affect the rotation base computed in Fig. 3, note the example in Fig. 4. Assume the loss rates for all assignment classes are 10 percent annually and

the accession lead times for this example are 20 weeks. The loss rates of 10 percent cause the requirement to increase by 2295 personnel.

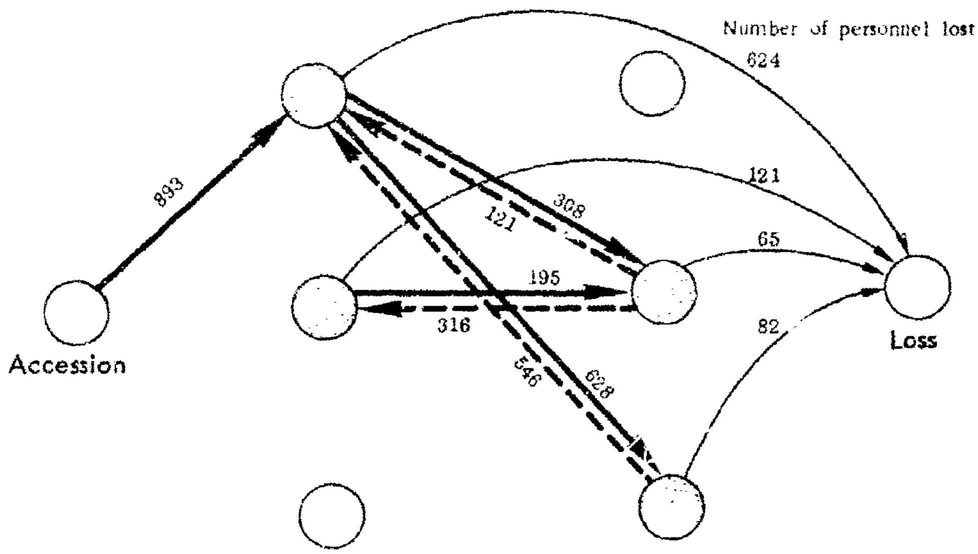


Fig. 4 -- Example problem with retention considered

Note that the effect the retention rate in an AFSC has on the rotation base depends on fungibility and also on the geographical balance of requirements. It is always desirable to retain transferable personnel; however, low retention rates are acceptable in non-retrainable AFSCs required overseas but surplus in ConUS. Note that when losses are considered, personnel in ConUS assignment class 2 always arrive there after a tour in ConUS assignment class 1 and a tour in overseas assignment class 2.

TOUR ALTERNATION POLICIES

In practice, personnel returning to ConUS from short-tour areas overseas are generally assigned to long-tour areas on their next overseas assignment. This "tour alternation" practice is so far accounted for only in the eligibility factor.

A paper on Army personnel assignment policies by Sorenson* includes the variables of the Kagan model and, in addition, controls the portion of the force that can be assigned between various areas. The Sorenson model handles the "alternation" constraints by increasing the number of tour areas or states in the network description of the rotation process. Assume there are two overseas areas and that assignments can be of only three types:

1. Area 1 to ConUS to either Area 1 or Area 2
2. Area 2 to ConUS to Area 1
3. Area 2 to ConUS to Area 2

Policy constraints can be introduced by specifying the maximum percentage of the force that can receive assignments of type 1, 2, or 3. For instance, let β_2 and β_3 specify the percentage of the force that may receive assignment patterns 2 and 3. Figure 5 presents the network description of this situation.

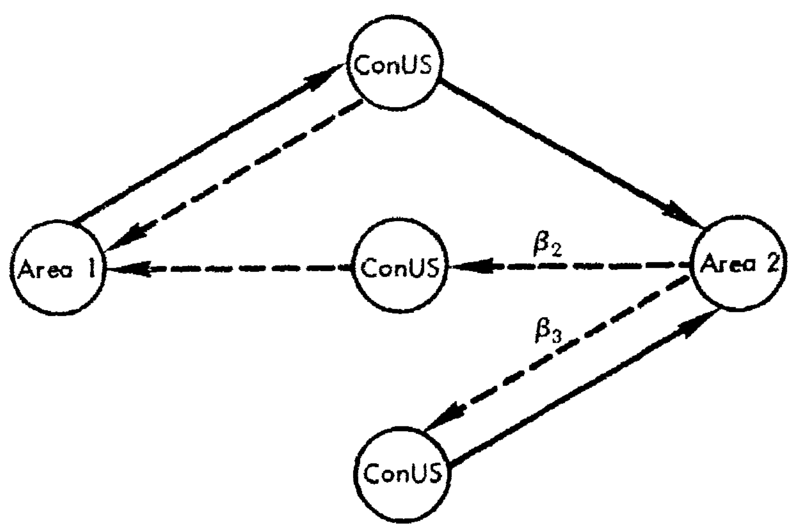


Fig. 5 -- Network description of controlled tours

*Sorenson, op. cit.

In the Sorenson paper the policy constraints are specified as equalities and there is no minimization objective. For various numerical values of the policy parameters, other measures of system performance are derived.

Introducing tour alternation constraints in the RAND model can be accomplished by increasing the size and complexity of the rotation network. This can be done by splitting the ConUS tour area into M - 1 tour area pairs (ConUS, Overseas tour area i), i = 2, ..., M - 1, where it is necessary to control return assignments from any of the M - 1 overseas tour areas into any of M - 1 overseas tour areas.

Again let b_i = number of personnel required in tour area i.

ℓ_i = tour length in location i.

X_i = number of personnel present in location i.

y_{ij} = personnel flow from location i to location j.

Since the number of personnel required at each location is not less than b_i, $X_i \geq b_i$. Total flow out of each overseas location is X_i/ℓ_i or $X_i = \ell_i \sum_j y_{ij}$, i overseas, and thus

$$\sum_j y_{ij} \geq \frac{b_i}{\ell_i}, \quad \text{for } i \text{ overseas.}$$

Arcs would then connect node i to each ConUS "tour area," and these arcs would be upper bounded by the number that could be reassigned to overseas tour area j following an intervening ConUS tour from tour area i. From (ConUS, tour area i) arcs would lead only to assignments in overseas tour area i.

With the assumption that the number eligible for some tour is a fraction of the number <u>required</u> at a node, the alternation policy constraints can be stated as $y_{ij} \leq \beta_{ij} b_i$. The model will then minimize the total number of military personnel required to support the overseas bases, and this minimization will be accomplished subject to requirement constraints, rotation constraints, and the tour alternation policy constraints.

It is apparent that decomposing one state into several states, and imposing additional constraints on personnel flow can only increase the minimum value of the objective function. That is, making assignment policies more restrictive creates a requirement for a larger rotation base.

APPLICATIONS OF THE ROTATION BASE MODEL

The model described here is a tool to yield an estimate of the rotation base requirement given tour lengths, manpower requirements, eligibility factors, and cross-training times. The model can obviously be used solely to derive this estimate. The estimate can be obtained by dealing with all career fields of the Air Force simultaneously or, for finer detail, by dealing sequentially with associated groups of AFSCs. In the former case one would expect cross-training between major career fields to be minimal. The decompositions treated in the second approach would be suggested by analyzing a matrix of cross-training times.

Parametric analyses of tour lengths, eligibility factors, numerical requirements, and even rotation policy or command reorganization are also possible with the model. If, for example, certain positions are to be eliminated from the Air Defense Command, the Rotation Base Model will indicate how this will affect the rotation base and will also indicate where the problems occur. There are two alternative methods of meeting overseas requirements in any assignment class. One is to retain a pool of personnel in that class in ConUS; the other is to cross-train ConUS personnel into that class. If cross-training into some assignment class is prohibitively long, it will be economical to retain appropriate personnel in ConUS--even if their specialty is not required in ConUS. This generates an "excess" of personnel.

There are elements concerning rotation that have not been introduced in this discussion but that can easily be included explicitly in the formulation. These elements include training school capacities, cross-training costs, pipeline times, and introduction of tour alternation policies by creating additional "states."

The Rotation Base Model is relatively fast, simple to use, and produces self-explanatory output. Input data exist and are already used for estimating the required rotation base. With proper understanding of its assumptions and criteria, this model can be helpful in analyzing rotation policy.

Appendix A

QUANTITATIVE AND LOGICAL STRUCTURE OF THE ROTATION BASE MODEL

The Rotation Base Model described in this Memorandum obtains more accurate estimates by considering substitutability between AFSCs. Personnel in one AFSC may be entered into training for assignment to another AFSC. This Appendix provides the mathematics describing this view of the rotation process and indicates the network structure equivalent to these mathematical statements.

One may wonder why it is necessary or desirable to formulate this problem as a network flow problem when it very obviously is a straightforward linear programming problem. In a rotation problem with 50 assignment classes and 20 tour areas, there may easily be many thousands of variables and constraints. A problem of this size is simply not amenable to solution and a variety of sensitivity analyses, given computational equipment now available. Using the Out-of-Kilter algorithm, however, a network flow problem consisting of several thousand arcs can be solved rapidly. Moreover, in performing sensitivity analyses, the Out-of-Kilter algorithm, which is a primal-dual algorithm, can be started with a previous optimal solution, thereby diminishing time required to obtain a new optimal solution.

Thus, while there are computational efficiencies to be gained from posing the problem as flow in a network, formulating constraints requires more care. We have already pointed out (p. 13) that in a network one variable cannot be constrained as some function of another variable. Moreover, constraints on sums of flows in a network cannot be imposed directly. In a linear programming problem a constraint of the form

$$\sum_j y_{ij} \geq \frac{b_i}{\ell_i}$$

is straightforward. In a network, however, only constraints on individual arc flows may be imposed. Therefore, to deal with flow on a group of arcs emanating from some node, i, one must introduce an

artificial node, i', and an arc (i, i'). The group constraint may then be written

$$y_{ii'} \geq \frac{b_i}{\ell_i} .$$

Assume that all bases have been aggregated into M "tour areas" of the same tour length and tour type, and that the tour areas are indexed by j. Assume that K assignment classes (groups of AFSCs, grades and skill levels considered together) may be present at each of the M tour areas. There are then KxM assignment-class/tour-area pairs, or nodes. The KxM nodes can be indexed sequentially by column, $i = 1, 2, \ldots K, K + 1, \ldots, KxM$.

For each node, i, originating in an assignment-class/tour-area pair, (k, j), let [i] denote either the assignment class k, or the tour area j, corresponding to node i. The context will make clear which is desired.*

Let b_i = number of personnel required in assignment class [i] in tour area [i].

X_i = number of personnel assigned to assignment class [i] in tour area [i].**

ℓ_i = standard tour length in overseas area [i].

ℓ_k^1 = average ConUS tour length served by personnel in assignment class k.

α_k = percentage in assignment class k eligible for overseas assignment.

y_{ij} = number of personnel moving from node i to node j per unit time.

t_{ij} = time required to cross-train personnel from assignment class [i] to assignment class [j].

---

*For example, assignment-class/tour-area pair (k, j) yields the node index $K(j - 1) + k$. Node index i yields the assignment class i mod K, or if i mod K = 0, then k = K. Node index i yields the location i/K if k = K, or i/K + 1 if k < K.

**Since the problem is formulated in terms of <u>flows</u> in a network, X_i is an artificial construct and never actually appears during the optimization. Following the optimization X_i is computed for each node i by the relationship $X_i = \ell_i \sum_j y_{ij}$, and this value is indicated in the output reports.

Using this notation, the number of individuals in each assignment class must meet requirements,

$$X_i \geq b_i, \qquad \text{for every node } i.$$

As noted previously, personnel must leave overseas tour areas and return to ConUS at a rate that depends on the overseas tour length;

$$(1) \qquad \sum_{j \in \text{ConUS}} y_{ij} \geq b_i/\ell_i \text{ for each overseas node, } i.$$

The model assumes that all training takes place in ConUS. It attempts to meet manpower requirements at all areas while using minimum total manpower. Total manpower includes personnel in training, personnel assigned to meet requirements, and personnel excess to ConUS requirements but necessary in ConUS to support the rotation flow.

If personnel are in training between an AFSC required overseas and an AFSC required in ConUS, the model requires that sufficient additional personnel be made available to fill the training pipeline. This manpower component is

$$\sum_i \sum_j t_{ij} y_{ij}$$

for all flows, y_{ij}, reflecting assignment against requirements.

Recall that X_i denotes the number of individuals assigned to an assignment-class/tour-area pair, i. The second component of manpower is then ΣX_i, and the total personnel objection function to be minimized is

$$(2) \qquad \sum_i \ell_i \sum_j y_{ij} + \sum_i \sum_j t_{ij} y_{ij} .$$

If more personnel are available at a ConUS node than are required -- that is, only to support rotational flow -- the model allows those individuals to be entered into training pipelines for assignments to other AFSCs without requiring additional manpower to fill the pipelines. The assumption is that since they are excess in ConUS they can attend school prior to completing the normal tour. The cost in this case for a reassignment from AFSC i in ConUS to AFSC j overseas <u>should be</u>

max (ℓ_i^2, t_{ij}), where ℓ_i^2 is the average ConUS tour length for excess personnel; but for simplicity we assume ℓ_i^2 is equal to ℓ_i^1 and is always greater than t_{ij}. It is this less-costly substitutability of some classes of excess personnel in ConUS that makes manpower economies possible within this model and within the Air Force.

In a network problem, flow constraints may not be imposed on sums or groups of flows, but only on individual flows. The constraint (1) is treated by creating an "artificial" node, i', and imposing the constraint

$$y_{ii'} \geq b_i/\ell_i.$$

The "cost," ℓ_i, is imposed on the arc (i, i'), thereby indicating that when b_i/ℓ_i personnel leave node i each period, the number of personnel present at node i to support their flow is

$$\ell_i \, b_i/\ell_i = b_i,$$

thus meeting requirements.

In dealing with ConUS nodes, three conditions arise. Flow overseas is restricted by the eligibility of the AFSC group for rotation; ConUS requirements in the AFSC must be met; and if excess personnel are present, they must be made available for training at reduced manpower cost.

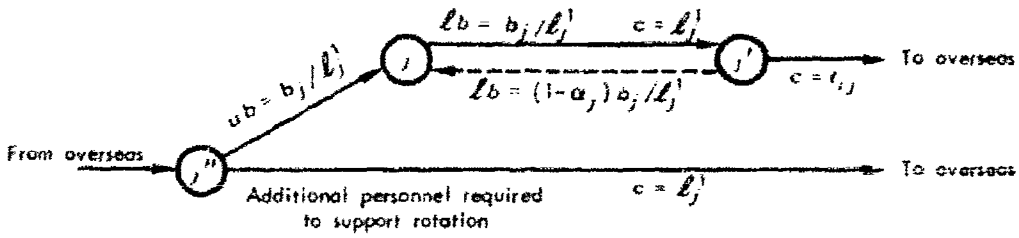
Figure 6 indicates the treatment of ConUS nodes for these conditions. To insure that requirements at ConUS nodes are met, an artificial node j' is constructed for each ConUS node j, and a lower bound of b_j/ℓ_j^1 is placed on the arc (j, j'). This insures that b_j people are present at j.

The lower bound

$$(1 - \alpha_j)b_j/\ell_j^1$$

on the arc (j', j) insures that of the personnel required at j, no more than the eligible fraction, $\alpha_j \cdot b_j/\ell_j$, are assigned overseas.

If overseas requirements dictate that this ConUS assignment class, j, just supply more personnel each time period than $\alpha_j \cdot b_j/\ell_j$, personnel in excess of b_j must be assigned at node j. This is accomplished



ℓ_j^1 = average tour length of required personnel in ConUS assignment class corresponding to node j

ℓb = lower bound on personnel flow, 0 unless stated

ub = upper bound on personnel flow, ∞ unless stated

c = cost, 0 unless stated

b_j = requirements at node j

α_j = percentage eligible to rotate overseas in assignment class corresponding to node j

Fig. 6 -- Network treatment of flow at ConUS nodes

by creating the artificial node j'' which becomes a source of additional personnel, and upper bounding the arc (j'', j) by the requirement, b_j/ℓ_j^1. In effect the additional personnel assigned to node j are then assumed to be completely eligible for overseas assignment. That is,

$$\alpha = \alpha_k \text{ for } b_k \text{ personnel, and}$$

$$\alpha = 1 \text{ for } X_k - b_k \text{ personnel.}$$

Flow from node j to node k requires that a manpower pipeline of length t_{jk} be filled. Thus, every arc (j', k) has the cost t_{jk}. The arc (j, j') has the cost ℓ_j^1, indicating that to obtain one man per time unit through node j, one must keep ℓ_j^1 men at the node. Note that whenever $t_{jk} > 0$ the model will find it less costly in manpower to fill a requirement at node k from node j'', $(c = \ell_j^1)$ than from node j, $(c = \ell_j^1 + t_{jk})$. The economy may arise if $\alpha_j \cdot b_j/\ell_j$, the available resource at j, is sufficient to meet requirements at overseas nodes corresponding to assignment class [j].

Personnel retention is considered by assuming that a constant percentage of the manpower required at a base, b_j, is continuously lost to the Air Force. Let λ_j be the loss rate of personnel at all bases in assignment class j. The magnitude of the loss from each node is then $\lambda_j \cdot b_j$. The artificial node, j', associated with each overseas node then has an arc connected to a "loss" node, and flow on this loss arc is lower bounded by $\lambda_j \cdot b_j$. Losses at ConUS nodes may occur from either j'' or j' personnel; therefore, each ConUS node j has associated with it a third node, j''', with an arc (j', j''') accounting for the loss of required personnel and an arc (j'', j''') accounting for the loss of excess personnel. The arc connecting j''' to the loss node is lower bounded by $\lambda_j \cdot b_j$. To allow accessions to balance the system, the loss node is connected to the accession node, and arcs connect the accession node to those ConUS assignment classes to which new personnel may be assigned. Since time is required for a new accession to become qualified for a ConUS assignment, the arcs connecting the accession node and ConUS nodes carry costs that are the training lead times for the particular AFSC and skill level. This treatment of losses is indicated in Fig. 7.

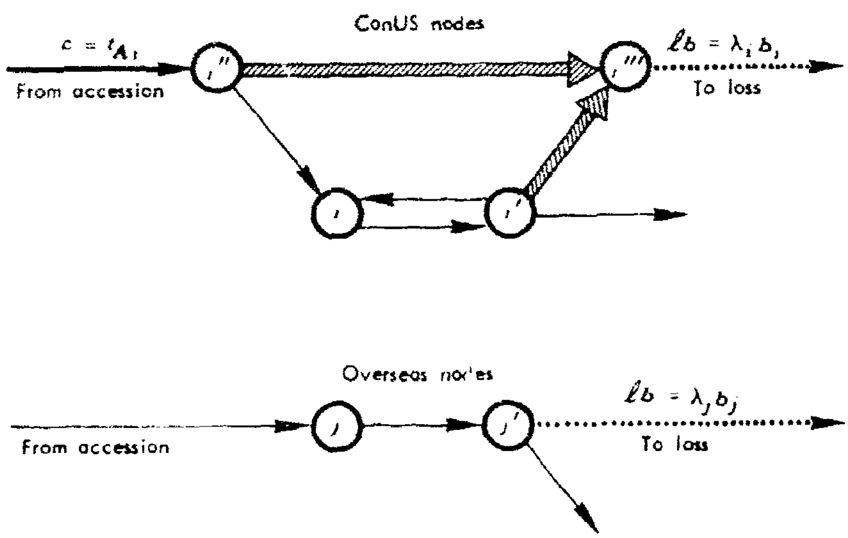


Fig. 7 -- Treatment of retention in one network

The simple conceptual network (Fig. 3) describing the rotation process becomes quite cumbersome in practice. Since assignment arcs are permitted whenever reassignment actions are possible, the number of arcs can proliferate furiously, and might easily overload the capacity of existing computers. To control this situation the model permits reassignment actions (arcs) only when $t_{ij} \leq T$, where T is an upper bound on cross-training time specified by the user. Thus in a fairly complex analysis, T might be set at 10 weeks rather than 30 weeks to control the number of cross-training possibilities, and hence the number of arcs.

Once the network is formulated the model utilizes the Fulkerson Out-of-Kilter algorithm to determine the minimum manpower required.*

The conceptual rotation network has been described. The actual program implementing the Rotation Base Model consists of three parts. The first portion accepts data inputs by assignment class and base, aggregates to tour areas, and creates the network of nodes and arcs. Given the basic input data the program first distinguishes between ConUS and overseas bases. It then creates tour areas by aggregating personnel requirements by assignment class at all bases of the same tour length and type. The assignment-class/tour-area pair becomes a node, while the aggregated personnel requirements, the tour length, and the loss rate determine the number of individuals who must rotate out of the node each month. By considering a matrix of cross training times, the program determines those assignment-class/tour-area combinations between which rotation is possible, and constructs all necessary arcs. The second portion uses the Out-of-Kilter algorithm to compute optimal personnel flow. The third portion is a report generator that produces requested manpower reports.

The program is written in FORTRAN IV and has been used on the RAND 7040/7044 system. It is currently dimensioned to handle 50 assignment classes and 20 tour areas, but this is arbitrary. The primary constraint on problem size is the number of possible arcs. The 32,000-word memory of the IBM 7044 will only permit consideration of about 2500 arcs.

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*Fulkerson, op. cit.

Appendix B

INPUT DATA, OUTPUT REPORTS, AND PROGRAM CONTROL

The Rotation Base Model requires four sets of data: manpower requirements, eligibility/availability factors, cross-training information, and loss rates and accession lead times.

MANPOWER REQUIREMENT DATA

The manpower requirement data identify the base (or tour area) name, tour length, tour type (used to distinguish between tour areas of the same length), AFSC designation, AFSC group, or name of the assignment class, and the personnel required in that assignment class in that tour area.

Data of this type are shown in Table 3, Appendix C. The input format for requirement data is shown in Fig. 8.

ELIGIBILITY/AVAILABILITY FACTORS

Not everyone in a ConUS assignment class can be rotated overseas. Personnel in student status, pending separations, controlled tours, recent additions, and other categories cannot be utilized. For each assignment class, the eligibility/availability factors state the average percentage of the ConUS based class that can be assigned overseas. A tour length estimate for this class is also required. This estimate is denoted the effective tour length, and is the average number of months this class spends in ConUS prior to the next overseas tour.

Table 4, Appendix C, shows a list of eligibility factors and effective tour lengths. The input format for this data is contained in Fig. 9.

CROSS-TRAINING DATA

The Rotation Base Model permits assignment of personnel between classes whenever this is allowed by cross-training. This data input is the time, in weeks, required to train an Airman from one class to another.

Each base card is followed by its assignment class requirements cards.

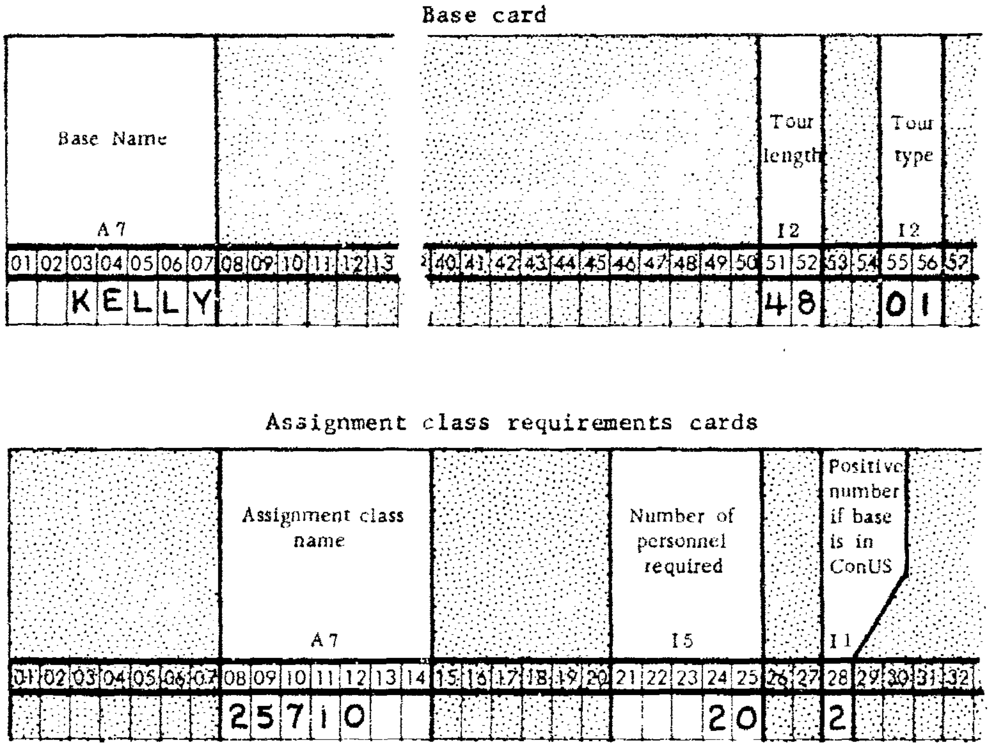

Fig. 8 -- Manpower requirement data by base and assignment class

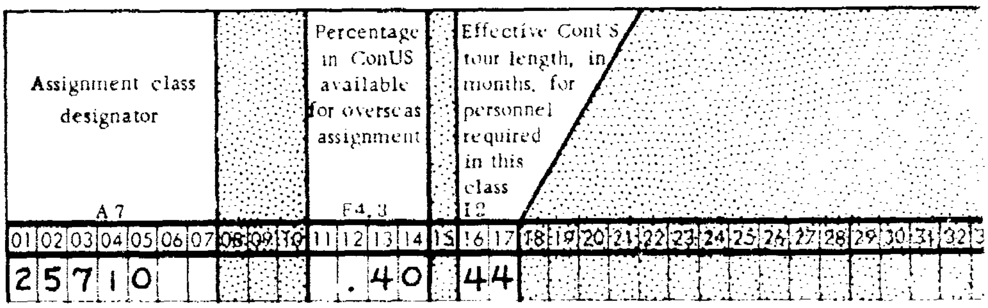

Fig. 9 -- Eligibility factors for overseas assignments and effective tour lengths by assignment class

A matrix of cross-training times is shown in Table 6, Appendix C. The input format for this training data appears in Fig. 10.

LOSS RATES AND ACCESSION LEAD TIMES

The model assumes that personnel in each assignment class at each location continually leave the Air Force to return to civilian life. Assumed also is that this loss rate may differ between assignment classes, but is constant within an assignment class across bases, and represents the annual fraction of the total class lost to the Air Force. Losses are compensated for by new accessions. The accessions are assigned only to ConUS locations and only after an appropriate lead time. Thus, each assignment class calls for a lead time, in weeks, that reflects all actions required to bring a recruit up to operational status in the assignment. Figure 11 represents the input format for these data.

All program input data can be printed out in report form. These reports contain data already described and are listed below.

1. Manpower requirements by tour area and assignment class.
2. Cross-training times.
3. Eligibility factors and effective tour lengths by assignment class.
4. Loss rates and accession lead times by assignment class.

There are also reports describing the number, type, and location of personnel in the system after a solution has been obtained.

5. Total number of personnel in each assignment class assigned to each tour area. Personnel in ConUS who are required in that assignment class only to support rotation are shown as excess.
6. Monthly assignments of personnel from each ConUS assignment class <u>to</u> all assignment classes and tour areas. One report is printed for each assignment class with personnel assigned to ConUS. Movements of required and excess personnel are indicated separately.
7. Monthly assignments of personnel to each ConUS assignment class <u>from</u> all assignment classes and tour areas. One report is printed for each assignment class with personnel assigned to ConUS.
8. Monthly personnel losses by assignment class and tour area.

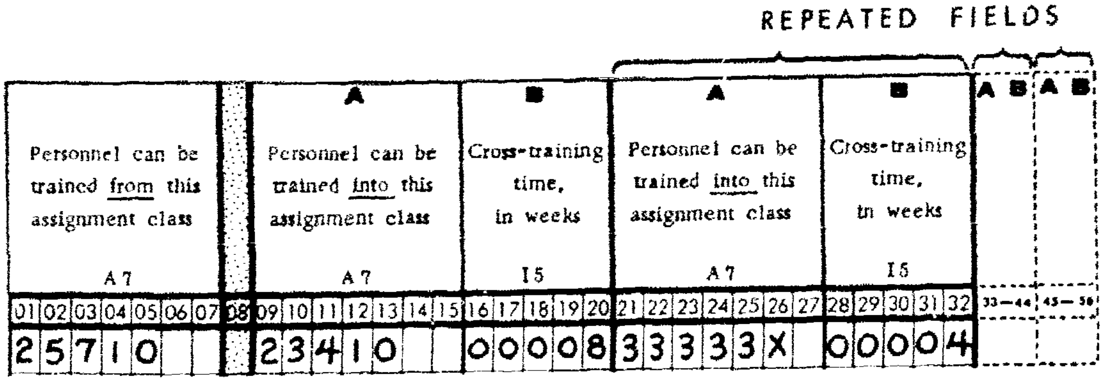

Fig. 10 -- Cross-training data

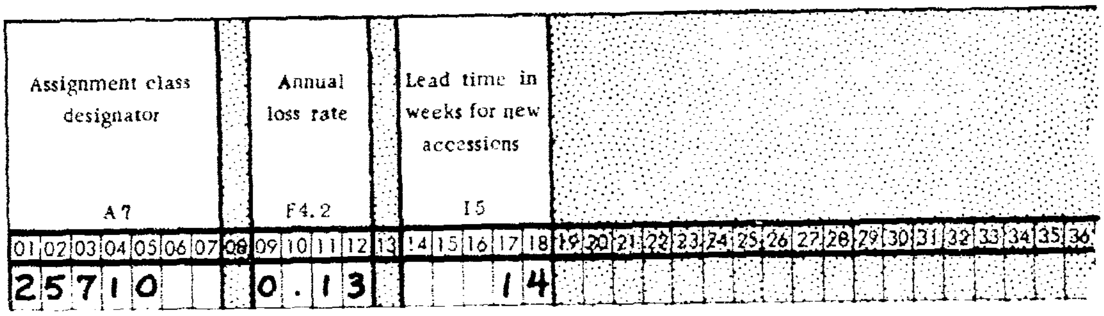

Fig. 11 -- Input format for accessions and losses

9. Monthly input of new accessions by assignment class.
10. Detailed description of the entire rotation network.

These ten reports can be selected through the report control card shown in Fig. 12. The program prints out several other self-explanatory reports when necessary.

Certain control data the model requires must also be supplied. These data are described below. The input format for this data is shown in Fig. 13.

1. The FORTRAN input unit from which manpower requirement data are to be read.
2. The FORTRAN input unit from which cross-training data are to be read.
3. The system utility (tape or disc) unit that can be used for temporary storage during program execution.
4. The FORTRAN output unit on which the network description can be saved, if desired.
5. A decision variable that determines whether accession and loss data are to be introduced and used in the rotation situation.
6. Within the model assignment possibilities are introduced whenever cross-training makes this possible. Reassignment will not be allowed if the required cross-training time is above some upper bound. This upper bound, in weeks, must be stated.

The input data may also include a title card containing any 72 characters of alphabetic and numeric information in Cols. 1 to 72.

Arrangement of the input data sections is shown in Fig. 14. Each section must be completed by a card with "END" in Cols. 1 to 3.

Manpower requirem'ts by tour area and assignment class	Cross-training times	Eligibility factors and effective tour lengths by assignment class	Loss rates & accession lead times by assignment class	Assignment of personnel by assignment class and tour area	Monthly personnel assignments		Monthly personnel losses by assignment class and tour area	Monthly input of accessions by assignment class	Detailed description of the rotation network
					From ConUS to overseas	From overseas to ConUS			
01	02	03	04	05	06	07	08	09	10
1	1	1	1	1	1	1	1	1	1

Fig. 12 -- Report control card

FORTRAN input unit				"1" if accession & loss data is to be used	Upper bound on allowed cross-training time in weeks
For reading base data	For reading cross-training data	For storing temporary data	For output of intermediate network data		
I2	I2	I2	I2	I2	I2
01 02	03 04	05 06	07 08	09 10	11 12
0 5	0 5	1 4	0 7	0 1	5 2

Fig. 13 -- Model control card

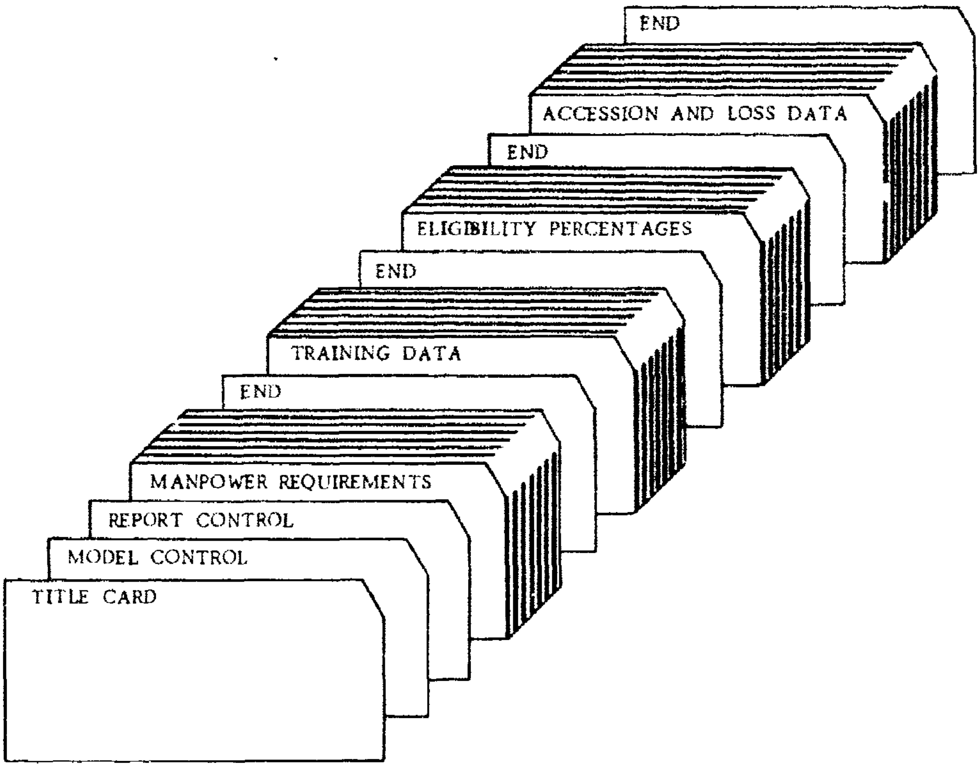

Fig. 14 -- Input data arrangement

Appendix C

AN ILLUSTRATIVE ROTATION PROBLEM

The following hypothetical rotation problem illustrates the use of the Rotation Base Model. Assume that each of the AFSC groups listed constitutes an assignment class, and that geographical manpower requirements are given by Table 3.

Table 3

GEOGRAPHICAL MANPOWER REQUIREMENTS

AFSC	ConUS	Pacific (24-mo tour)	SEA (13-mo tour)	USAFE (24-mo tour)	Misc (24-mo tour)
206X0	7000				
605X0	9500				
645X0	3500		2000		
647X0	5500				
303X0	7000	1500	1000	250	100
304X0	4000	100	2500	150	235
702X0	4000	200	300	500	750
291X0		100	1500	750	
202X0		1000	1000	100	
461X0		500	6500	200	500

ConUS tour lengths and overseas eligibility factors for each assignment class are shown in Table 4.

Table 4

TOUR LENGTH AND ELIGIBILITY FACTORS FOR CONUS PERSONNEL

AFSC	ConUS Tour Length (Months)	Percentage Eligible For Overseas Assignment
206X0	30	0.65
605X0	30	0.70
645X0	30	0.65
647X0	30	0.65
303X0	22	0.35
304X0	22	0.40
702X0	22	0.70
291X0	22	0.40
202X0	22	0.50
461X0	22	0.35

Assume that no cross-training or assignment between AFSC groups is permitted and that no personnel are lost to the system--retention rates are 100 percent in all AFSCs. Table 5 shows the minimum number of personnel required in this situation by AFSC and location. The total personnel required is 88,323, of which 20,460 are excess to ConUS requirements but needed to support rotation.

Table 5

PERSONNEL AT EACH ASSIGNMENT CLASS/TOUR AREA

	Tour Area					
AFSC	ConUS	Pacific	SEA	USAFE	Misc.	Total
206X0	7,020					7,020
605X0	9,480					9,480
645X0	4,680					4,680
	1,170[a]					
647X0	5,580					5,580
303X0	8,096	1,560	15,041	312	96	11,078
304X0	6,380	96	2,535	216	312	10,397
	858[a]					
702X0	4,004	216	338	528	840	5,926
291X0		96	1,521	840		5,889
	3,432[a]					
202X0		1,032	1,014	96		4,892
	2,750[a]					
461X0		528	6,591	216	528	20,183
	12,320[a]					
Total	65,770	3,528	15,041	2,208	1,776	88,323

[a]Excess to ConUS requirement.

CROSS-TRAINING

If cross-training and assignment between AFSCs are permitted, the total number of personnel required should be reduced. Assume cross-training times are given by Table 6 and that all other data remain the same. Table 7 shows the resulting optimal assignment of personnel. In addition to the 79,350 personnel assigned to bases, 1,655 are in training pipelines. This yields a total requirement of 81,005 personnel, compared with 88,323 with no cross-training.

Table 6

CROSS-TRAINING TIMES IN WEEKS

From/To	206X0	605X0	645X0	647X0	303X0	304X0	702X0	291X0	202X0	461X0
206X0	0						4		20	
605X0		0					4			12
645X0		4	0	12			4			12
647X0		4	0	0			4			12
303X0				12	0	0	4	6	10	4
304X0		4		12	0	0	4	6	10	4
702X0	10	4	4	12			0	4	4	8
291X0		4	4		12	12	4	0	10	12
202X0	6						4	6	0	
461X0		4	12	12			4			0

The personnel movements between all tour areas and AFSCs are cumbersome to depict in a diagram. The model provides a separate report of the total number moving from each ConUS AFSC to all AFSCs in all tour areas, and from all overseas tour areas and AFSCs returning to each ConUS AFSC.

Table 7

PERSONNEL AT EACH ASSIGNMENT-CLASS/TOUR-AREA
WHEN CROSS-TRAINING IS ALLOWED

AFSC	Tour Area					
	ConUS	Pacific	SEA	USAFE	Misc.	Total
206X0	7,020					7,020
605X0	9,480					9,480
645X0	3,510		2,028			5,539
647X0	5,580					5,580
303X0	11,242	1,560	1,014	312	96	14,308
	84[a]					
304X0	4,004	96	2,535	216	312	7,163
702X0	4,004	216	338	528	840	5,926
291X0		96	1,521	840		3,264
	807[a]					
202X0		1,032	1,014	96		2,142
461X0		528	6,591	216	528	18,929
	11,066[a]					
Total	56,797	3,528	15,041	2,208	1,776	79,350

[a]Excess to ConUS requirements.

ACCESSIONS AND LOSSES

Assume that in addition to the situation considered thus far we recognize personnel are lost to the Air Force according to the loss schedule in Table 8, and that lead times for new accessions are as shown in that table.

Table 8

LOSS RATES, LEAD TIMES FOR NET ACCESSIONS

AFSC	Annual Loss Rate	Lead Times (Weeks)
206X0	0.50	10
605X0	0.50	18
645X0	0.50	12
647X0	0.50	10
303X0	0.50	11
304X0	0.50	9
702X0	0.50	9
291X0	0.50	10
202X0	0.50	10
461X0	0.50	11

One would intuitively expect the total number the system requires to increase as the loss rates increase. This is in fact the case. Table 9 indicates that 78,885 personnel are assigned at all bases, plus 7530 personnel in training pipelines, yielding a total requirement of 86,415 compared to 81,005 in the previous case, which did not consider losses.

The introduction of accessions and losses raises interesting points. Note that loss rates of 50 percent in all AFSCs increase the total manpower requirement by only 6 percent, and that the number of personnel assigned to ConUS AFSCs actually decreases. Table 10 explains this decrease in ConUS assignees by indicating that personnel losses in ConUS occur from the excess. In this extreme example it is possible to man the ConUS requirements with new enlistees in only 9 to 12 weeks. The model, therefore, finds it optimal to bring in new personnel for ConUS assignments, reassign them overseas, return them to ConUS and discharge them.

Table 9

PERSONNEL AT EACH ASSIGNMENT-CLASS/TOUR-AREA
WHEN ACCESSIONS AND LOSSES ARE CONSIDERED

	Tour Area					
AFSC	ConUS	Pacific	SEA	USAFE	Misc.	Total
206X0	7,020					7,020
605X0	9,480					9,480
645X0	3,510		2,028			5,538
647X0	5,580					5,580
303X0	7,062	1,560	1,014	312	96	10,044
304X0	6,380	96	2,535	216	312	22,289
	12,750[a]					
702X0	4,004	216	338	528	840	5,926
291X0		96	1,521	840		2,457
202X0		1,032	1,014	96		2,688
	546[a]					
461X0		528	6,591	216	528	7,863
Total	56,332	3,528	15,041	2,208	1,776	78,885

[a]Excess to ConUS requirements

Table 10

MONTHLY LOSSES BY AFSC AND TOUR AREA

	Tour Area				
AFSC	ConUS[a]	Pacific	SEA	USAFE	Misc.
206X0	290				
605X0	394				
645X0	143		82		
647X0	225				
303X0	290	61	39	9	
304X0	165		104	4	9
702X0	165	4	9	17	30
291X0			61	30	
202X0		39	39		
461X0		17	269	4	17

[a]All losses in this column are due to excess personnel.

The pattern of new accessions is shown in Table 11.

Table 11

ACCESSION OF NEW PERSONNEL

AFSC	No./Month
206X0	446
605X0	
645X0	152
647X0	347
303X0	351
304X0	949
702X0	273
291X0	
202X0	
461X0	

Figures 15a, 15b, and 15c suggest how optimal personnel movements change as additional factors are included. Figure 15a indicates AFSC groups 303X0 and 304X0, and movements between the five tour areas. Figure 15b shows the personnel flow in those AFSCs and areas when cross-training is permitted but accessions and losses are not. Notice that ConUS AFSC 303X0 supplies much of the overseas requirement for overseas AFSC 304X0.

Figure 15c indicates personnel movements out of ConUS when accessions and losses are considered. For clarity, losses are only indicated from the miscellaneous tour area. In reality they occur in all areas. While return flows to ConUS are omitted from Fig. 15c, the reports indicate that there is no personnel movement from overseas back to ConUS AFSC 304X0. Thus the picture that emerges is one of 949 new enlistees per month moving into training for ConUS AFSC 304X0. In this example training requires only 9 weeks. Following a 22-month tour in ConUS, AFSC 304X0 personnel are reassigned to other AFSCs overseas since the cross-training table indicates this type of reassignment is possible in a number of cases. Rather than reassigning overseas personnel to ConUS 304X0 (unnecessary because of relatively low ConUS requirements and almost impossible because of cross-training), the model discharges this stream of personnel.

(a) With no cross-training

(b) With cross-training

(c) With cross-training and losses

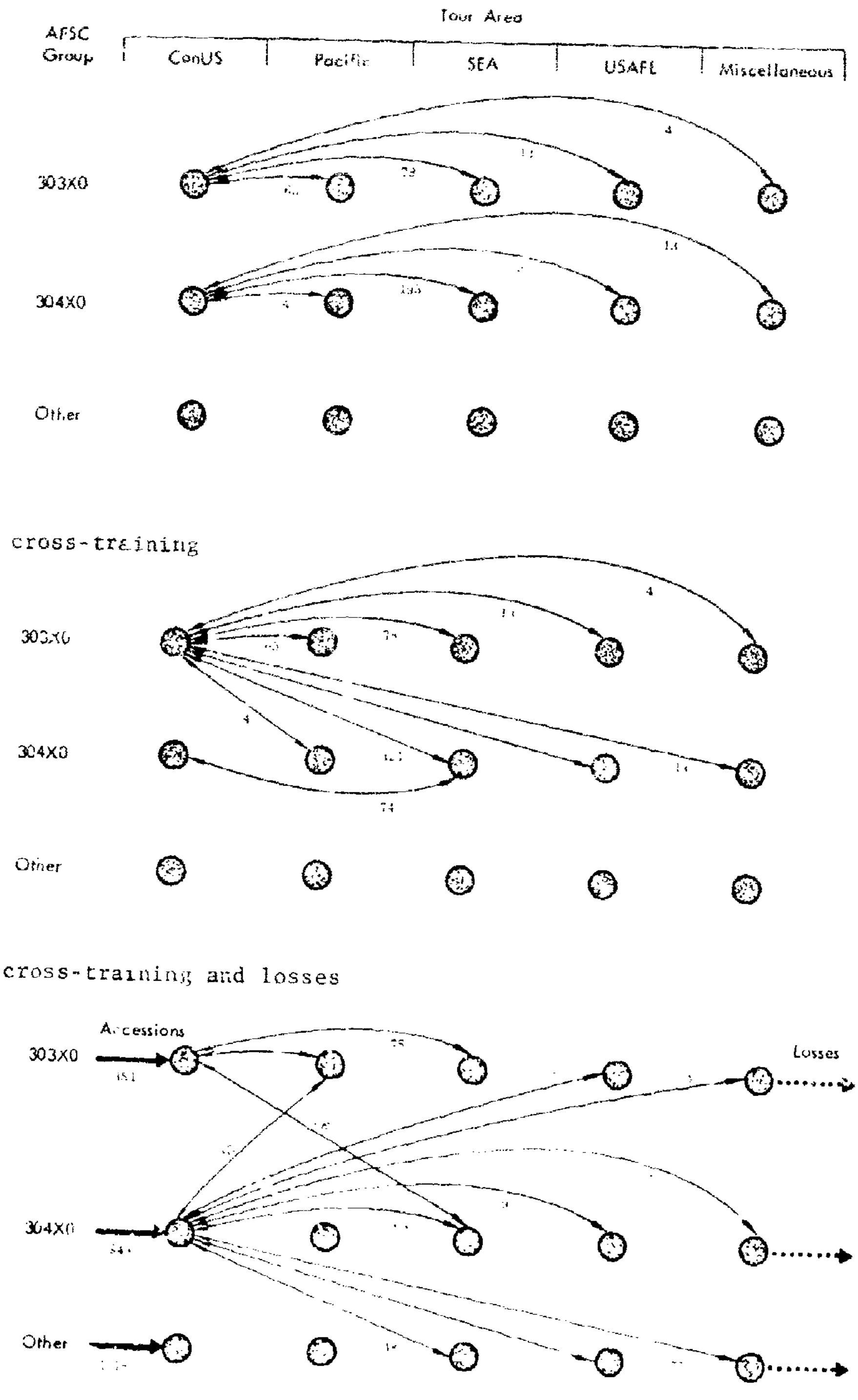

Fig. 15 -- Partial monthly personnel movement

Analysis of this type for selected groups of AFSCs may indicate significant assignment constraints and policies that the Rotation Base Model ignores. This will then lead to model refinements and a more useful operating tool.

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10. ABSTRACT

Description of the RAND Rotation Base Model for estimating Air Force manpower needs caused by rotation. The Fulkerson Out-of-Kilter Algorithm (P-1825) is used to solve the personnel flow problem that results from formulating rotation as a network. There are about 40 significant airman career areas and 10 overseas tour areas (groups of bases with similar characteristics and tour length); the model is set up to handle 50 classes and 20 areas. The nodes of the network each represent an assignment class (such as "Staff sergeant, jet engine mechanic, skill level 5") at a particular tour area; the arcs connect nodes between which reassignment is permitted. To the model now used by the Air Force Military Personnel Center, the RAND model adds the factors of personnel substitutability, cross-training, actual personnel loss rate, accession rate, and initial training time.

11. KEY WORDS

Air Force
Computer programs
Personnel
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